The Off-Axis Detector

Measuring θ_{13} with the NUMI beam

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Talk Outline:

- *Goals*
- *Site.*
- *Detector Concepts.*
- *Beam.*
- *Physics Potential*
- *Status and Schedule.*

Goals

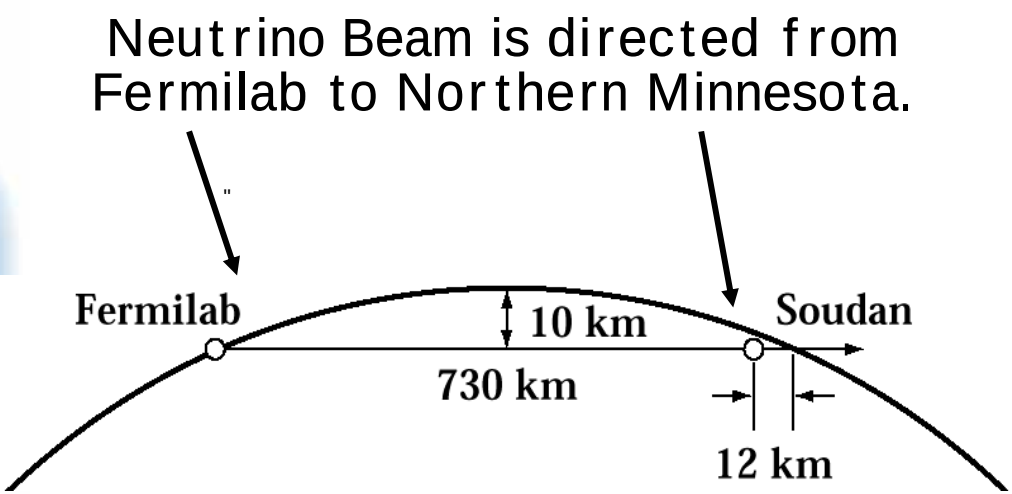
- ***Primary goal: Find evidence for $\nu_\mu \rightarrow \nu_e$ determining $\sin^2(2\theta_{13})$ to a factor of 2.***
- ***Longer Term: Determine mass hierarchy.***
- ***Very Long term: Precision measurement of the CP-violating phase δ***

ν_μ–> ν_e Appearance.

- ***Go off the axis of the NuMI beam to get a low-energy narrow-band beam near the atmospheric oscillation maximum (proposed by Brookhaven in 1995)***
  - **ν_e appearance maximum**
  - **ν_μ CC largely disappears**
  - **Higher-energy NC disappears**
- ***Build a detector optimized for electron detection***
- ***Increase the beam flux ✕ detector mass***
- ***Work at a long baseline to maximize matter effects***

NuMI Beam


Soudan
Duluth
MN
Lake Superior
WI
Lake Michigan
Madison
MI
IA
Fermilab
IL
IN
MO

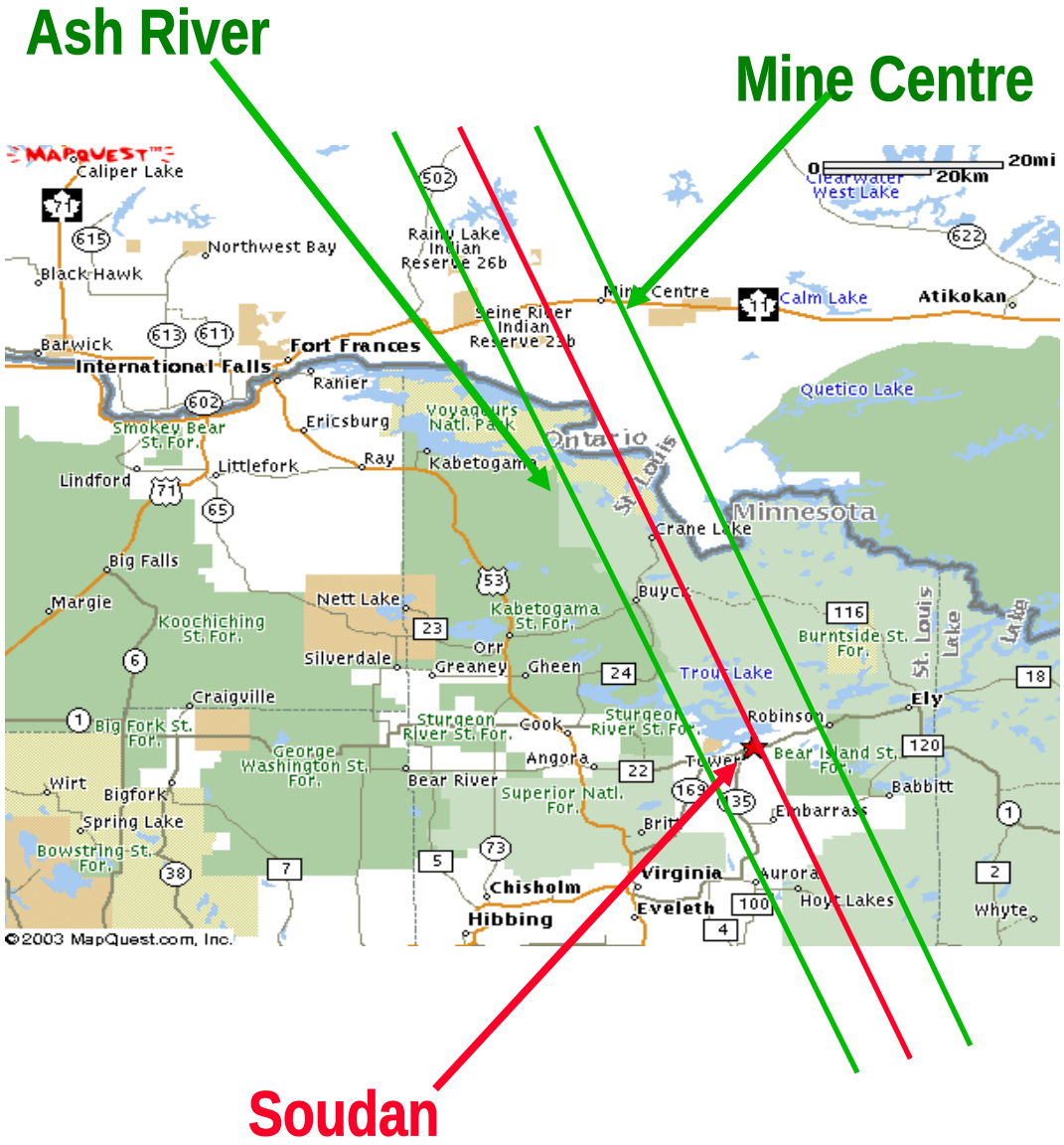

Neutrino Beam is directed from Fermilab to Northern Minnesota.
Fermilab
10 km
Soudan
730 km
12 km

Site of Off-Axis Experiment.

Detector will be on the surface located at a maximum distance form Fermilab and still inside the US.

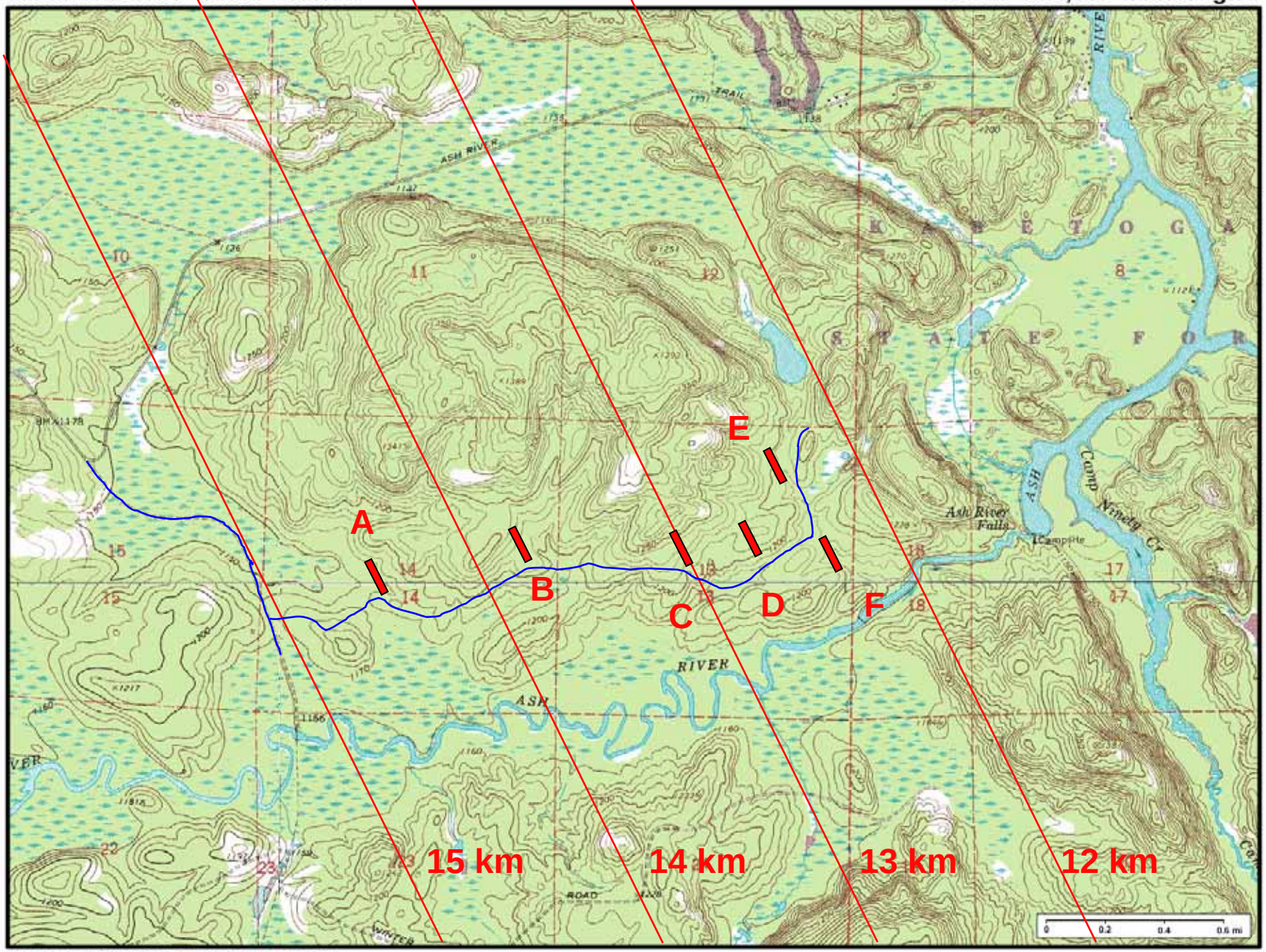
Ash River is the currently preferred site. Permissions are being sought to proceed.

L = 820 km



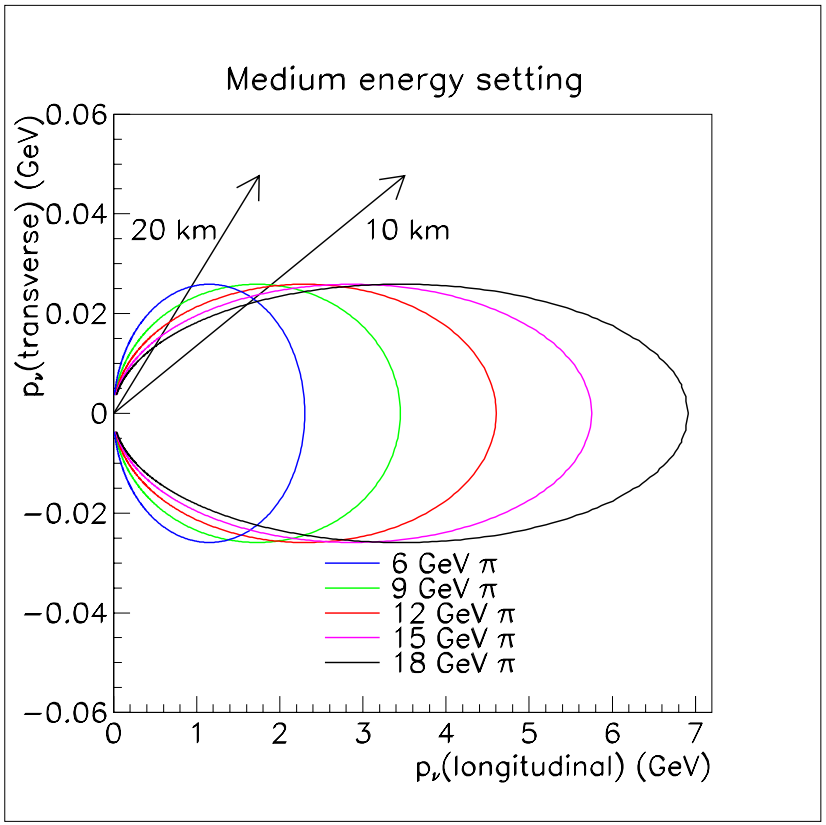
Minnesota DNR - ToMO Service

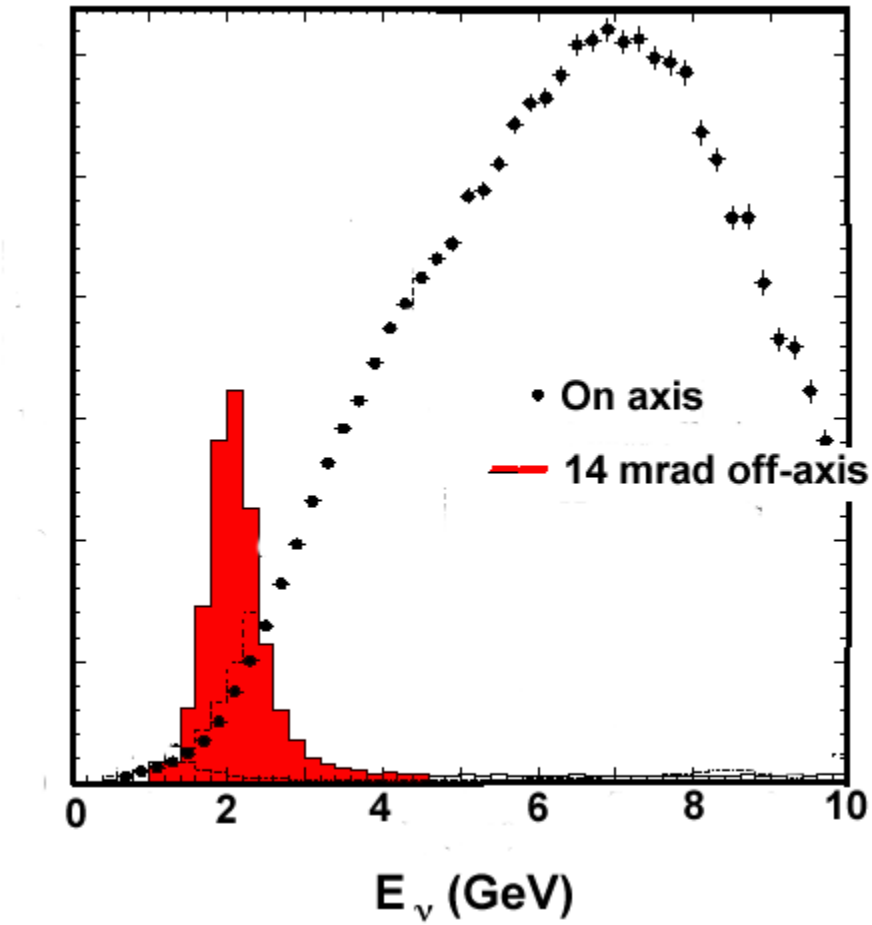
USGS 1:24,000 Quadrangles



Maps shown: Ash River NE, Daley Bay, Ash River SE, Ash River SW.

Neutrino Energy Spectrum





Off the main beam axis there is a narrow energy spread.

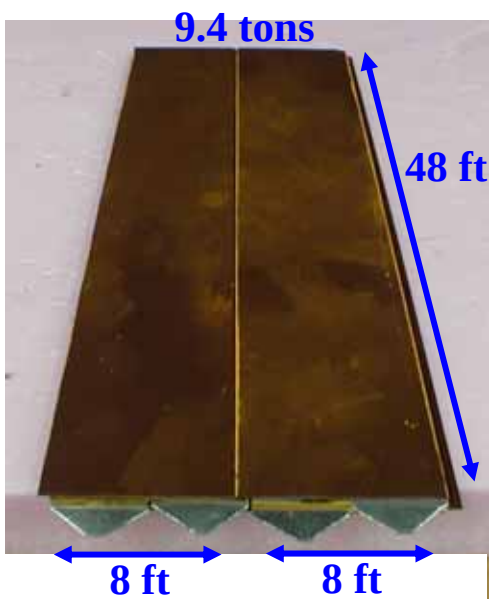
Detectors

- ***Sampling calorimeter.***
- ***Large Scale – 50 ktons.***
- ***Need clean low-energy electron identification –***
  - **WOOD. It's low cost, abundant and nearby.**
- ***On surface, not in a mine.***
  - **Can do this since beam spill is 10 micro-seconds and coincident background rates are small.**
- ***Design to be low cost.***

Two detectors proposed scintillator and resistive plate chambers both use particle board as the passive material.

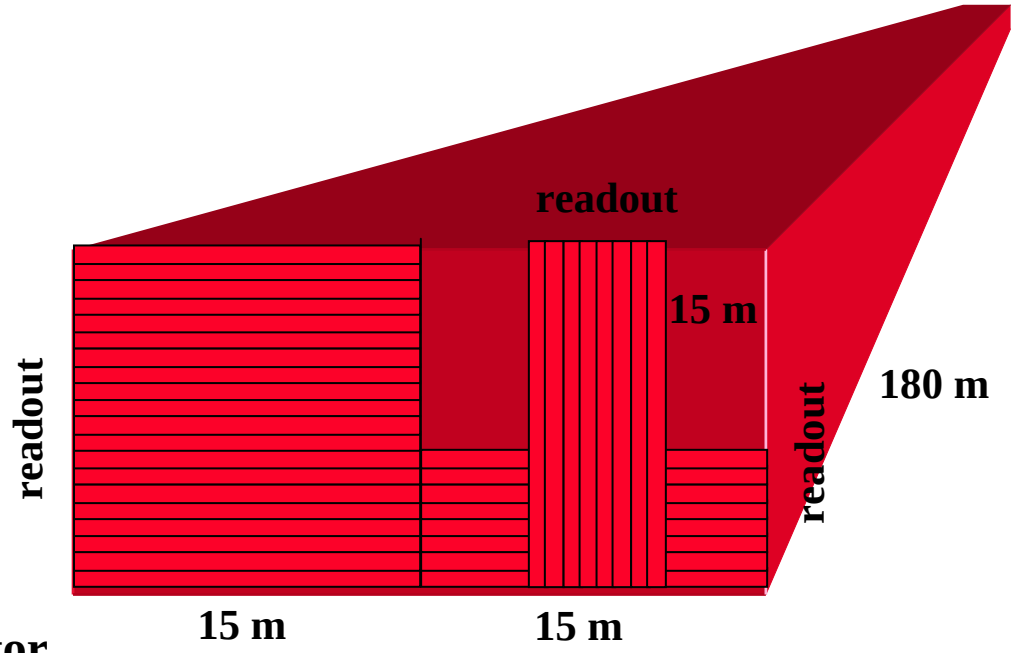
The Scintillator Detector.

- *Height 15 m*
- *Width 30 m*
- *Scintillator Active Detector*
- *Particle Board Passive Material (density .6 - .7)*
- *Alternating horizontal and vertical detector planes*
- *1/3 radiation length between detector planes*

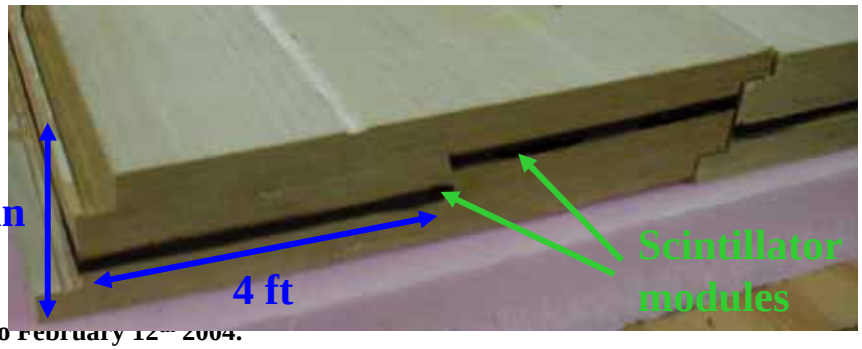


6 = 1 plane

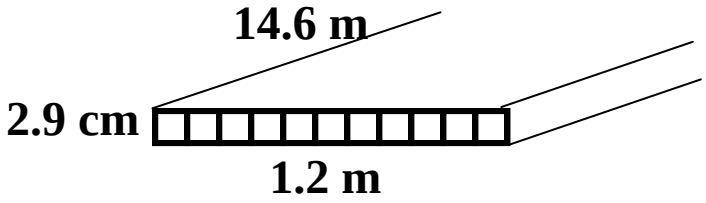
5300 = detector



800 planes = detector

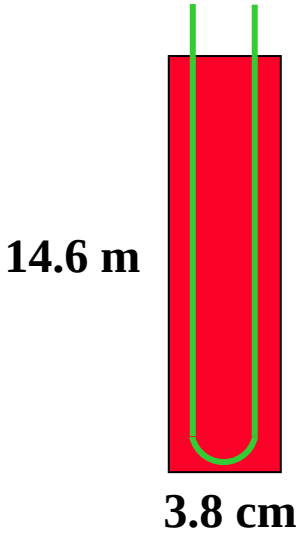


Scintillator Container



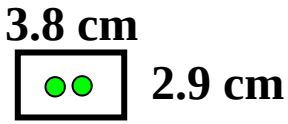
1 module – Extruded PVC

- 32 cells/module
- 1 scintillator layer/plane
- 0.09 tons/module (unfilled)



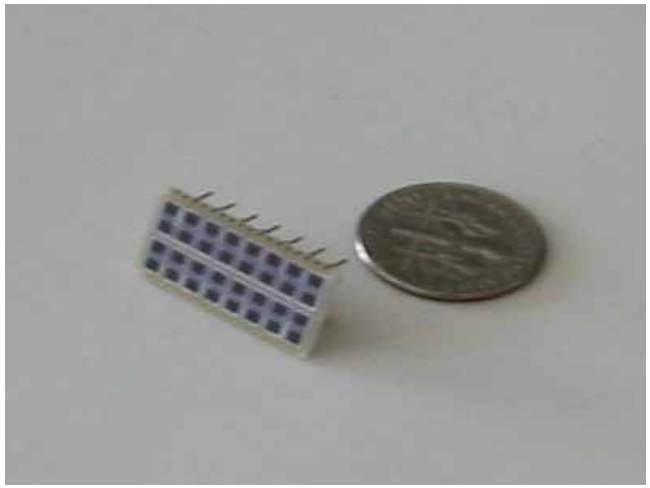
Wavelength shifting fiber – 0.8 mm

U loop - 4 times photons at far end as single fiber



1 cell

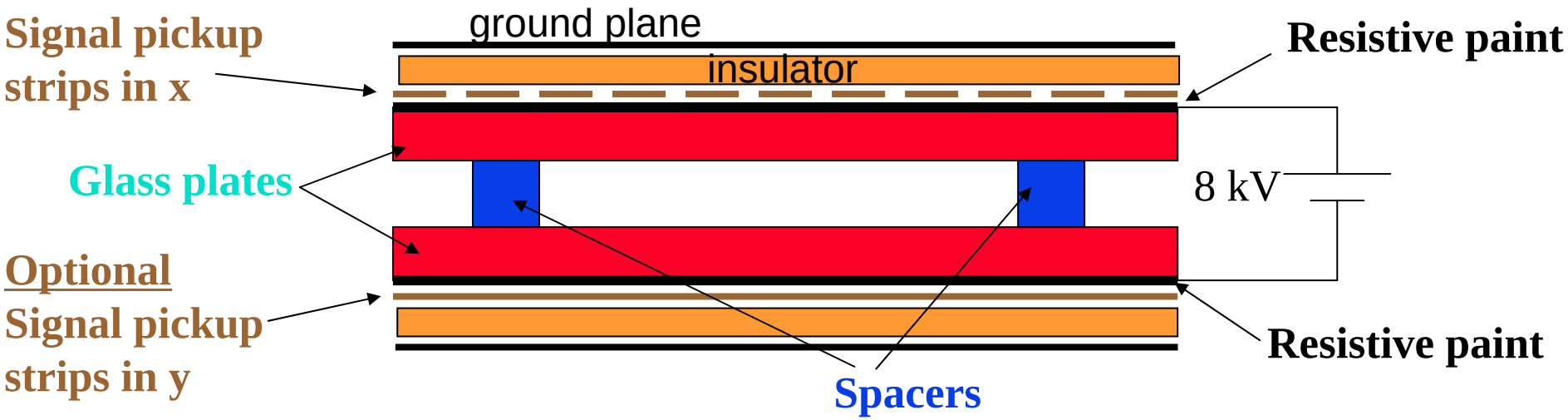
- 1.5 mm outer wall
- 1 mm inner wall
- WLS read out for scintillator



Use pixelated APD to readout strips.

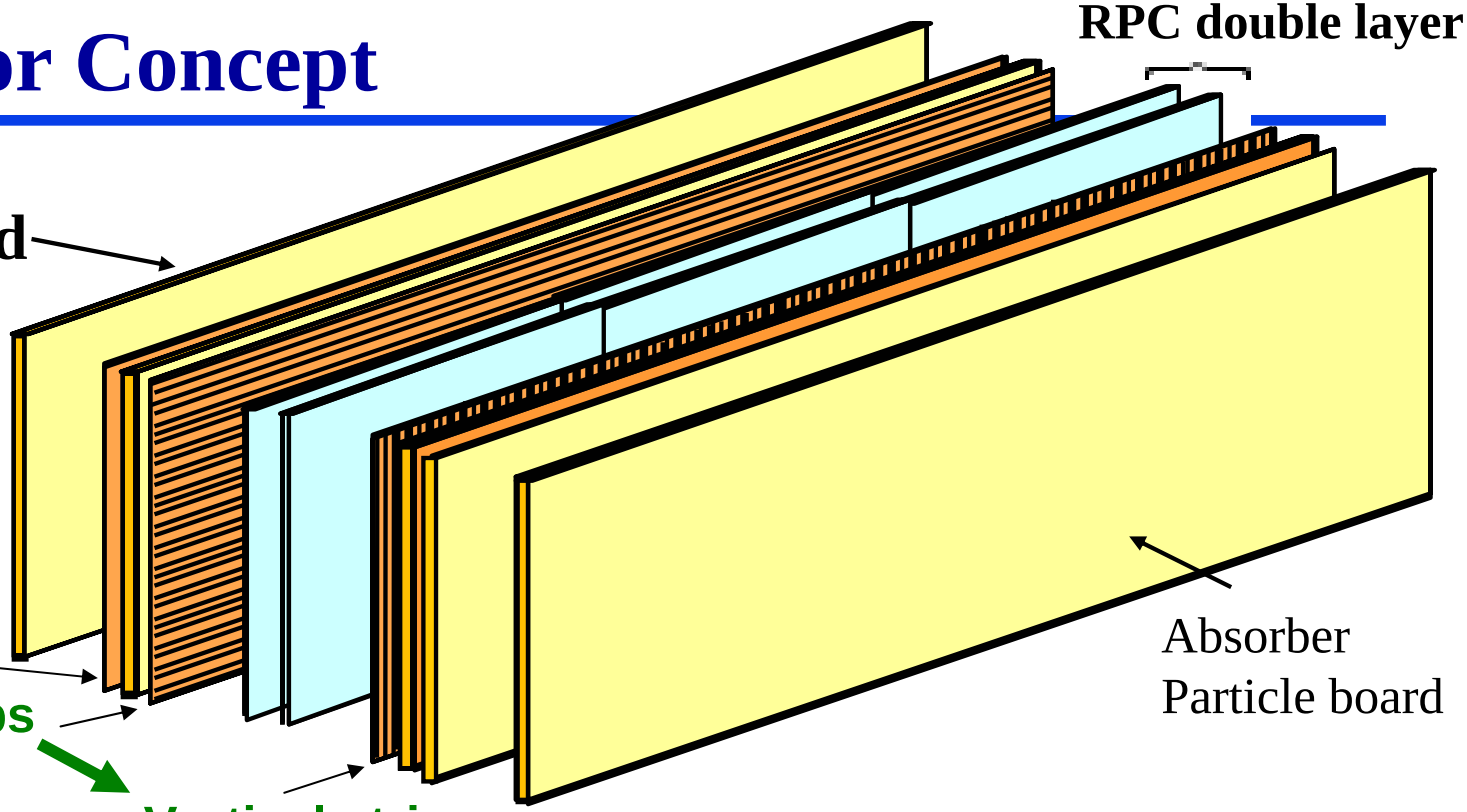
RPC Concept

Use BELLE glass RPC detector as a fundamental element.
Paired detectors to get maximum efficiency.
Basic glass chamber size 2.84 ✕ 2.34 m².
Six chambers are ganged together to make 15m wide detector.



Basic detector structure

Detector Concept



Absorber
Particle board
8 ft x 28 ft
"magic" max size
From industry,
1 inch thick
0.7 gm/cc

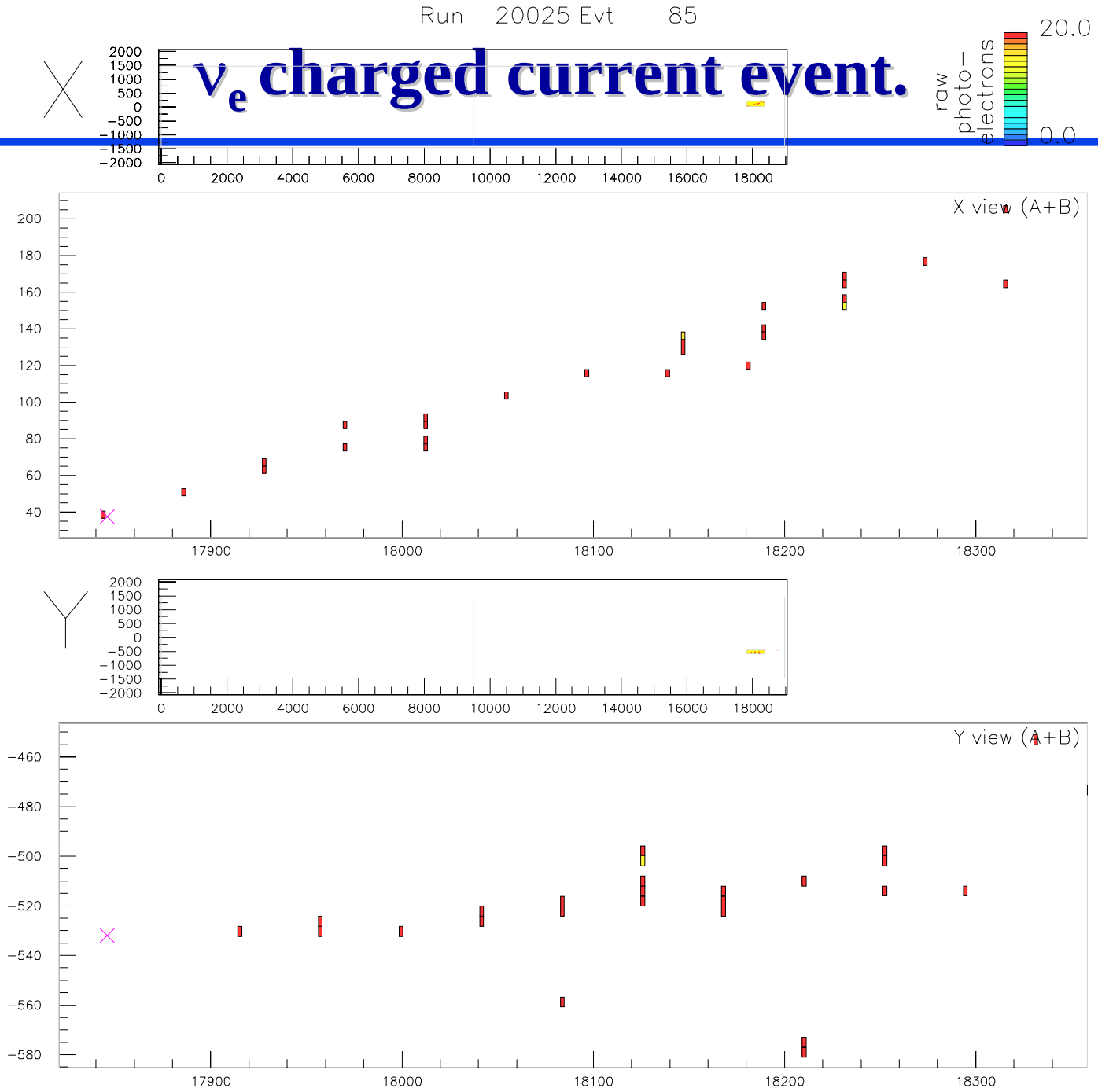
Ground plane
Horizontal strips
About 3.7 cm wide,
17 micron Cu foil
on Particle Board
64 channels

Vertical strips,
About 4.4 cm wide,
Cu on Particle Board
3 x 64 = 192 channels

596,000 m^2 RPC.
3.7 million channels.

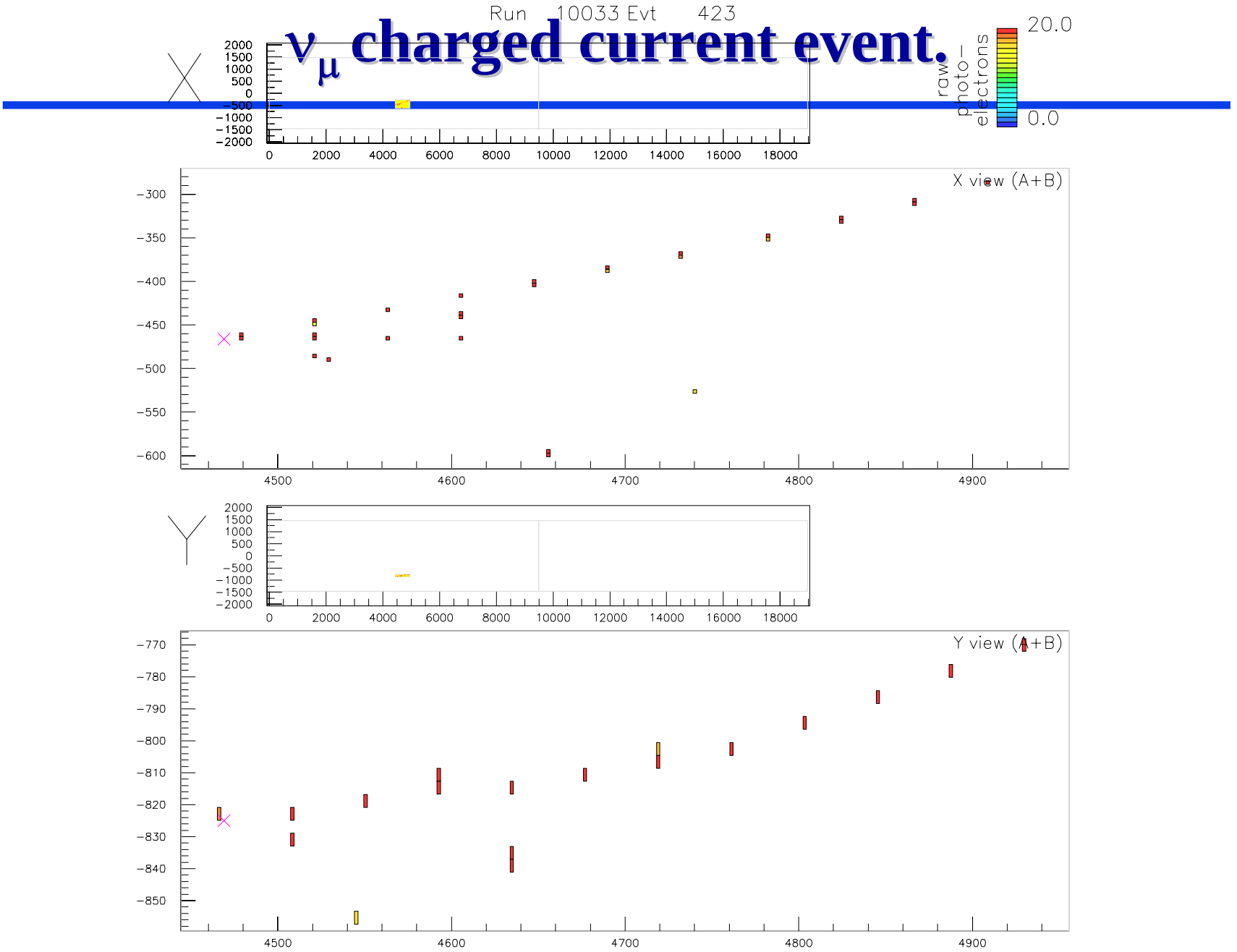
- *RPC's arranged in two layers to get full efficiency - 4 layers of glass,*
- *2 layers of strips on Particle Board, ground plane on opposite side.*

ν_e charged current event.



NOON2004 Tokyo February 12th 2004.

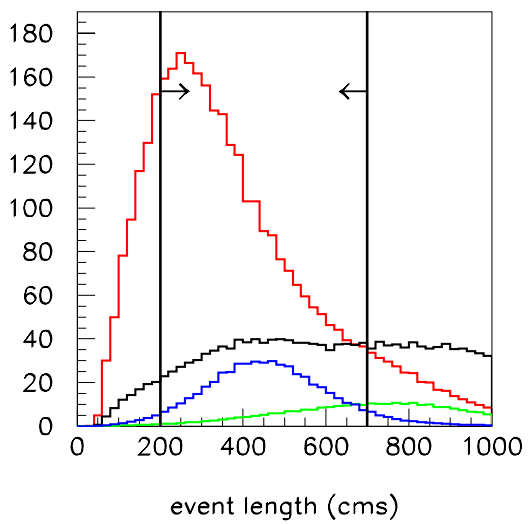
ν_μ charged current event.

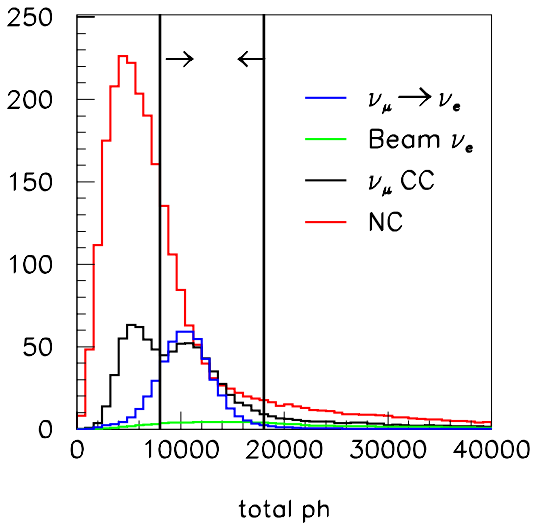


Method

Event length

Rejects ν_μ CC events



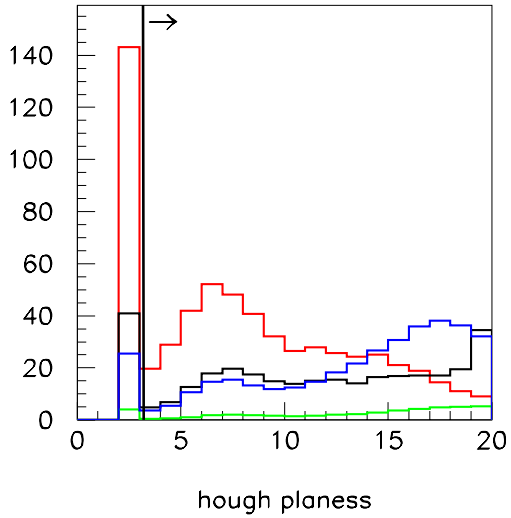


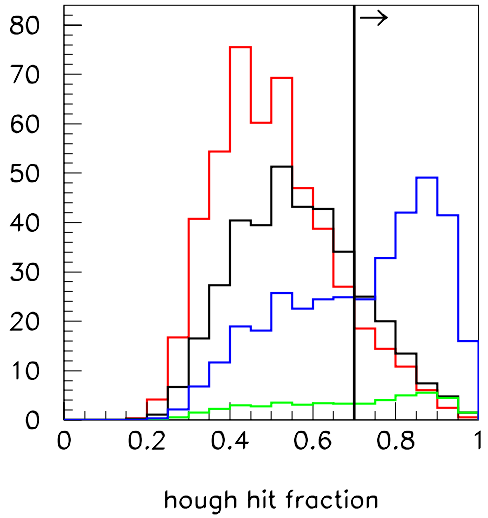
Total pulse height

Rejects high energy ν_e CC events and low visible energy events

Number of planes in the Hough track.

Requires a good track





Fraction of hits in the Hough track

Selects low-y or quasi-elastic events

and number of hits per plane etc.

Sensitivity

Full simulation with scintillator detector and beam assuming $\Delta m^2=0.0025$, $\sin^2 2\eta_{23}=1$ and $\sin^2 2\eta_{13}=0.1$.

ν_μ suppressed at 10^{-5}.
Neutral currents at 10^{-3}.
Beam ν_e at $2\ 10^{-3}$.
Detection of ν_e from oscillations 18%.

Signal/$\sqrt{\text{Background}}$ = 25.3 $\pm$ 0.4

What Beam do we Expect.

- *MINOS will start next year with 2 ✕10^{20} protons on target/yr.*
- *By 2009 expect this to have doubled.*
- *Further increases in intensity will require replacement of the 8 GeV booster with the super-conducting LINAC, the "Proton Driver" – see next talk. This could add another factor of 5.*

$P(\nu_\mu \rightarrow \nu_e)$ (in Vacuum)

- $P(\nu_\mu \rightarrow \nu_e) = P_1 + P_2 + P_3 + P_4$
  - $P_1 = \sin^2(\theta_{23}) \sin^2(2\theta_{13}) \sin^2(1.27\, \Delta m_{13}^2\, L/E)$
  - $P_2 = \cos^2(\theta_{23}) \sin^2(2\theta_{12}) \sin^2(1.27\, \Delta m_{12}^2\, L/E)$
  - $P_3 = J \sin(\delta) \sin(1.27\, \Delta m_{13}^2\, L/E)$
  - $P_4 = J \cos(\delta) \cos(1.27\, \Delta m_{13}^2\, L/E)$

  where $J = \cos(\theta_{13}) \sin(2\theta_{12}) \sin(2\theta_{13}) \sin(2\theta_{23})$ x

  $\sin(1.27\, \Delta m_{13}^2\, L/E) \sin(1.27\, \Delta m_{12}^2\, L/E)$

$P(\nu_\mu \rightarrow \nu_e)$ (in Matter)

$P(\nu_\mu \rightarrow \nu_e)$ is modified by matter effects

- *In matter, P_1 will be approximately multiplied by $(1 \pm 2E/E_R)$*
- *P_3 and P_4 will be approximately multiplied by $(1 \pm E/E_R)$,*
- *+ sign is for neutrinos with normal mass hierarchy or antineutrinos with inverted mass hierarchy.*

This is a $\pm$ 23% percent effect for NuMI

while it is about $\pm$ 10% for JPARC 1.

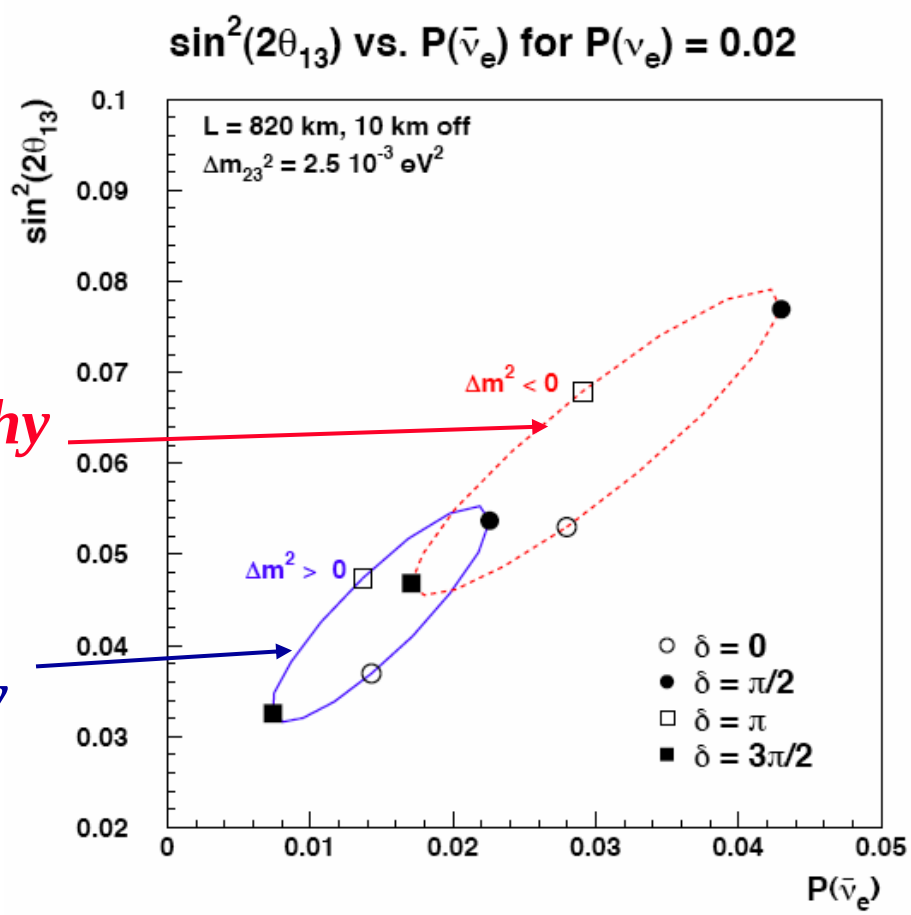
Magnitudes

- *For the long baseline measurement the off-axis, P1, P3 and P4 are all the same order of magnitude.*
- *We will measure an effective "$P(\nu_\mu \rightarrow \nu_e)$".*
- *Reactor experiments measure directly $P(\nu_\mu \rightarrow \nu_e)$ but have no sensitivity to hierarchy or to δ.*

Combine with results from other experiments to obtain hierarchy and δ.

Probability Plots

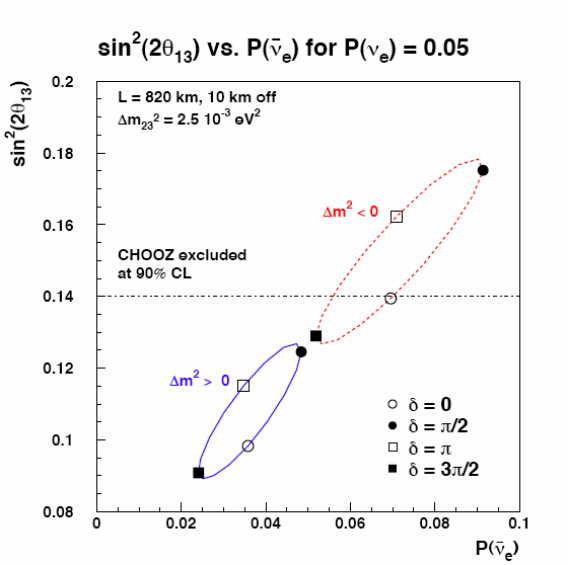
- ***Assume a value of $P(\nu_\mu \rightarrow \nu_e)$ and then show:***
  - **The possible values of $\sin^2(2\theta_{13})$, sign(Δm_{13}^2), and δ consistent with this measurement.**

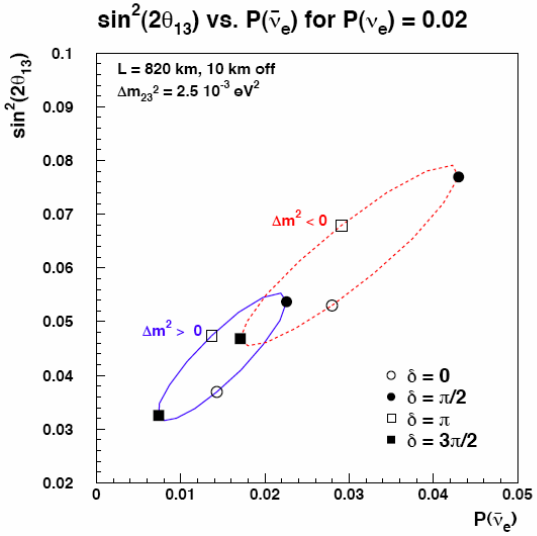


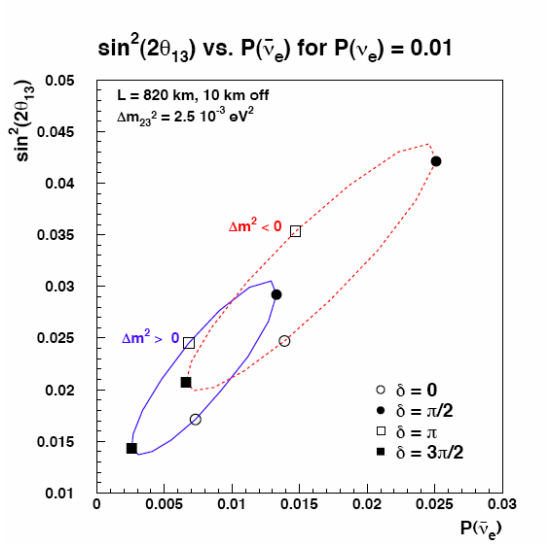
Normal hierarchy

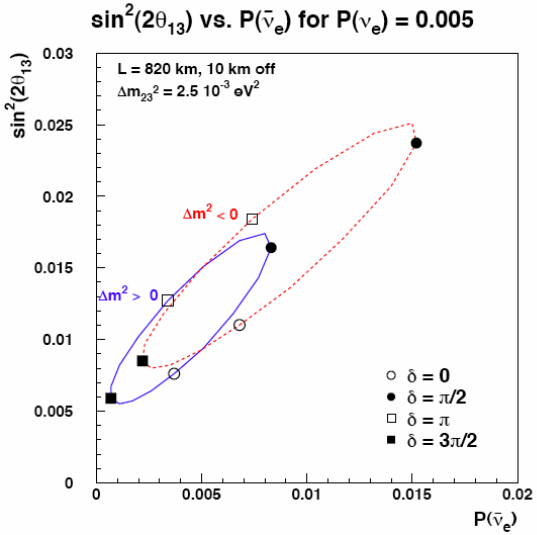
Inverted hierarchy

$P(\nu_\mu \rightarrow \nu_e)$ at 820 km

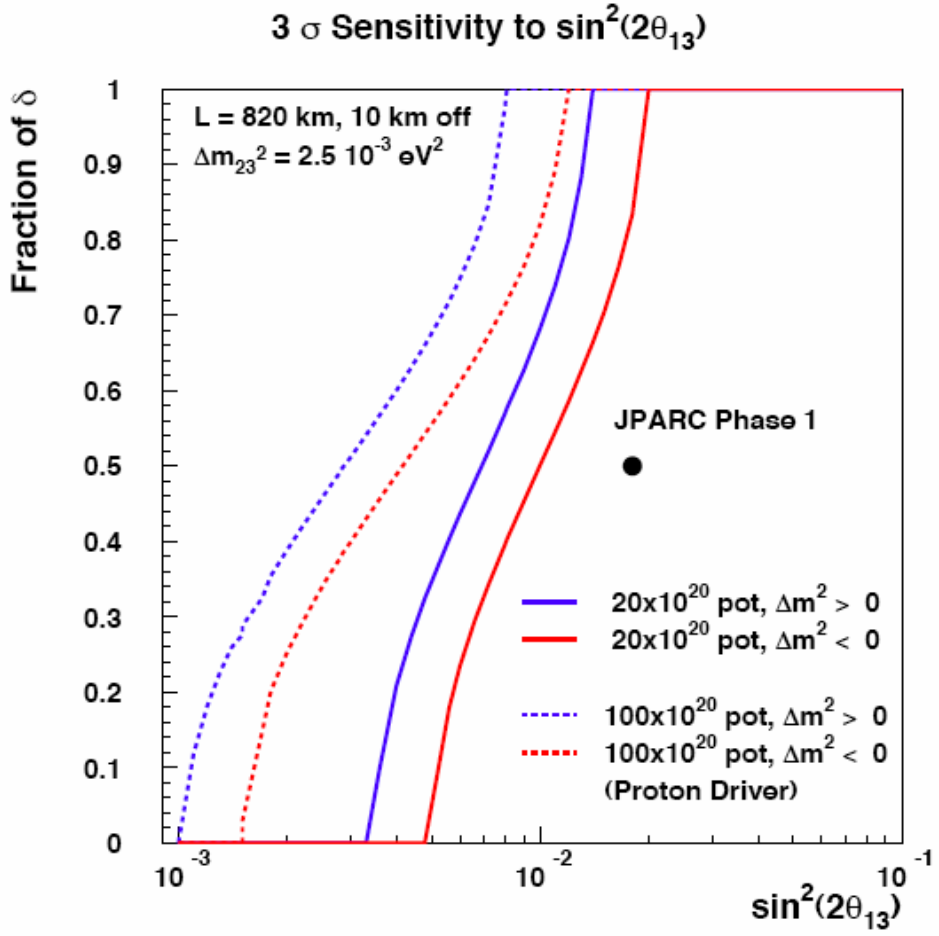






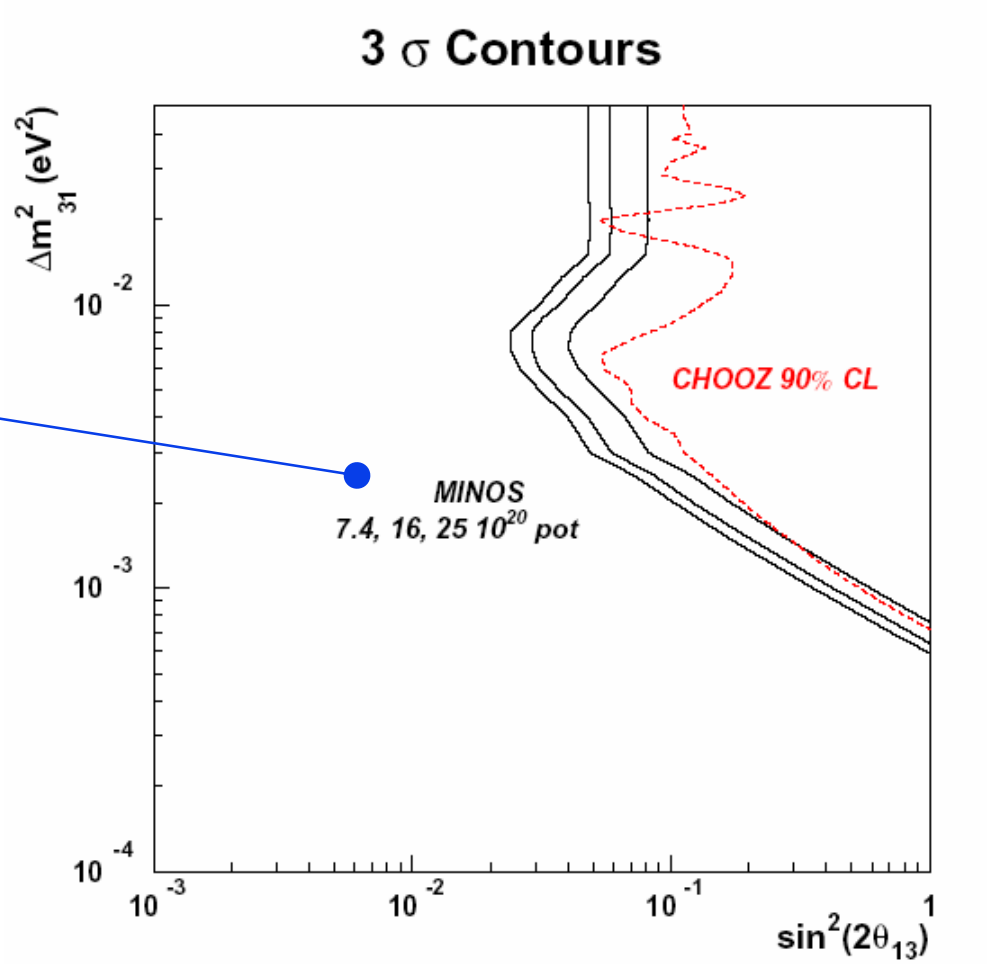


3 σ Discovery Potential for $\nu_\mu \rightarrow \nu_e$



$\nu_\mu \rightarrow \nu_e$ at 3σ Discovery

Off-Axis Goal



Status

- ***R&D proposal submitted.***
- ***Progress Report submitted to the Fermilab PAC in December.***
- ***PAC reaction:***
  - **"This can potentially become the future flagship experiment in an exciting neutrino physics program at Fermilab."**
  - **"Given the physics potential of the experiment and the significant detector cost involved, the Committee feels that some assistance from Fermilab for time-critical R&D needs leading to the proposal are justified."**
- ***Full proposal will in March.***
- ***Could start construction Oct 2006.***
- ***Could start taking data with 25% of detector in 2008.***